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INTERACTIVE VISUALIZATION OF COMPUTATIONAL FLUID DYNAMICS USING MOSAIC

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Abstract

The Web provides new methods for accessing information world-wide, but the current text-and-pictures approach neither utilizes all the Web's possibilities nor provides for its limitations. While the inclusion of pictures and animations in a paper communicates more effectively than text alone, it is essentially an extension of the concept of "publication." Also, as use of the Web increases, putting images and animations online will quickly load even the "Information Superhighway." We need to find forms of communication that take advantage of the special nature of the Web. This paper presents one approach: the use of the Internet and the Mosaic interface for data sharing and collaborative analysis. We will describe (and in the presentation, demonstrate) our approach: using FAST (Flow Analysis Software Toolkit), a scientific visualization package, as a data viewer and interactive tool called from Mosaic. Our intent is to stimulate the development of other tools that utilize the unique nature of electronic communication.

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A Scientific Expedition

Scientific Expedition is a term coined by Val Watson to describe an online, interactive exploration into data. Scientific Expeditions transcend the "publication" paradigm for providing information on the Web. Our goals for proposing the use of

Scientific Expeditions are:

- To make scientific data itself, rather than descriptions of research, directly available.
- To communicate the information using easy-to-use, standardized tools.
- To employ tools that use network bandwidth more intelligently.
- To propose that the use of this type of tool be accepted as a goal by NCSA and other organizations, and that it reach every public high school before the end of 1996.

Our example of this approach uses the *Flow Analysis Software Toolkit* (FAST).

The Visualization Tool: FAST (Flow Analysis Software Toolkit) (1)

FAST is a software package for the visualization of three-dimensional data, particularly Computational Fluid Dynamics data. It provides a variety of methods for examining data, such as plotting flow paths around an aircraft, color-mapping temperature on the surface, locating areas of a specified pressure, displaying vectors, and finding vortices. When a view or views are found which reveal important features of the data, an image can be generated, or an animation created.



FAST on HDTV Monitor.(2)

This image is from a visualization created by FAST. Clicking on the image will link you to a file of FAST-generated images (and one mpeg animation) on the NAS (Numerical Aerodynamics Simulation Division) Web server at NASA Ames.

Each time FAST is used, the session is recorded to file as a series of commands. This feature allows scientists to reexamine data they have viewed previously in FAST, without repeating the process of loading data and stepping through the commands previously issued. This is also the feature which makes FAST easily adaptable to use on the Web. Rather than putting an animation online, we are proposing that scientists share the entire FAST session, and thus the possibility for further analysis, with the scientific community. Because FAST can be driven by a script, the minimum necessary to do this is simply making the dataset and script available from HTML documents. What we propose, however, is the integration of Scientific Expeditions into Mosaic sessions, using visualization tools like FAST as data "viewers," in the sense that xv is an image viewer for Mosaic.

Using FAST for Scientific Expeditions

We have made some sample scientific expeditions available. They can be run by anyone who has a Silicon Graphics workstation, and the FAST software. Plans for making FAST available via Mosaic are being developed. It may or may not be available by the Web conference date. At present, it is available via COSMIC. The method for obtaining FAST will be kept current on the FAST home page. See How to Get FAST or the FAST home page (1) if you need to obtain the software.

The expeditions integrate FAST into Mosaic by defining FAST-related files as a mime type, x-fasttrek, which is returned for files with the suffix .FASTtrek. .FASTtrek files are passed to a shell script (called FASTtrek) which handles the details of sorting out datasets and scripts, making security checks, and sending the data and scripts to FAST. From the user's point of view, one simply clicks on a link, and the viewer, FAST, pops up and displays an animation, just as any other viewer displays its image or animation. But this viewer has advantages over other viewers:

- More information is transmitted while using less bandwidth.
- The actual dataset is transmitted, which permits the scientist or student to do further analysis.
- The scripting feature also allows interactive sessions, in which scientists at remote locations can view data simultaneously, passing control of the display back and forth. We use the term *Remote Collaboration* to describe this two-way interaction.

Scripting

In a later section, we will compare a set of animations to using FAST to view the same data. With that dataset, each animation is about two megabytes, while the entire FAST Expedition is less than one megabyte, and offers the user the ability to interact with the data. Script based animations are very small files, since they consist of a series of commands like the following:

```
file_IO: READ_FILE grid.bin
file_IO: FILE_TYPE FUNCTION
file_IO: READ_FILE scalar_field.bin
surfer: TYPE SCALAR
```

The above lines are sufficient to load a three dimensional grid of, for example, an aircraft, and a file containing values for pressure on the surface and in the surrounding space, and then display the surface of the aircraft with pressure color mapped on it.

```
surfer: NEW_OBJECT
surfer: DIRECTION I
surfer: RENDER CONTOUR_LINES
surfer: LOOP FORWARD
```

This second set of commands creates a simple animation through the pressure field surrounding the aircraft, similar to the illustration of a FAST animation shown below in the "FASTtrek Implementation Overview."

Developing the Implementation for Ease-of-Use and Security

Our original experiments used a simple implementation: FAST was invoked from a C shell script. The only thing a FAST user needed to do to run FAST scripts via Mosaic was to add a line to his .mailcap file to run csh when a .csh type was encountered. This approach got us in trouble with our security staff. If we encouraged people to run C shell scripts from Mosaic, they would be at risk of clicking on a hyperlink to a shell script that contained mischievous or harmful commands.

A second reason for deciding on a different approach was our goal of creating an easy-to-use, full-featured standard tool as a data "viewer" for Mosaic. This included providing a graphical user interface, and allowing for Remote Collaboration, the simultaneous viewing of a FAST session at multiple sites, with swapping of control. Therefore, we create a set of executables to be installed on each user's machine. We continued development with an awareness of the security risks inherent in a tool that permits users to bring groups of files to their machines, and run them without inspecting them. We found two risks specific to our implementation:

- The files sent in a FASTrek could contain an executable with an innocuous name, such as "fast," which could be invoked by users who have their current directory in their path. We prevent this by having FASTrek check for the location of FAST before extracting the files, and by using absolute path names.
- It is possible to send a system command from a FAST script. FASTrek searches and deletes any system commands from scripts it sends to FAST. While this removes one feature from FAST, it seems an acceptable sacrifice in the name of security.

FASTrek Implementation Overview

Users wishing to add FASTreks to the capability of Mosaic can implement this in one of several ways:

- Load an archive file that can be run as a C shell script which unloads its own contents, the FASTrek executables. This script also modifies the user's .mailcap and .mime.types files, and notifies the user of any missing elements in the configuration (such as not finding FAST in the executable path). To do this, select Options/Load to Local Disk, and copy FASTarchive.csh to a directory in your executable path. Then, in a shell window, cd to the directory and type

```
csh FASTarchive.csh
```

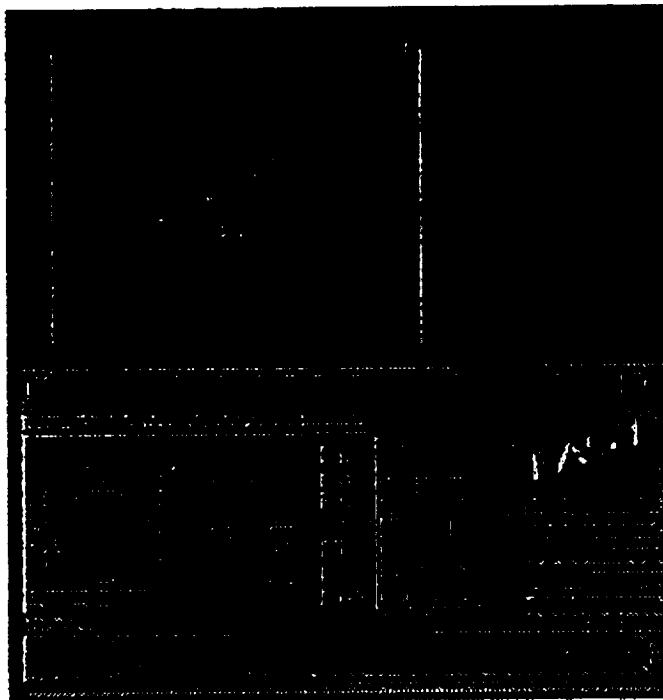
When installation is complete, select Options/Reload Config files and you will be ready to run FAST Expeditions.

- For those preferring to inspect and control any changes made to their machine, several approaches exist:
 - The C shell script that unpacks the archive is a short, simple set of

- commands at the head of the file, which can be examined;
- o The source files can be inspected or copied individually, or the executables can be copied individually: See FASTrek Executables. Users of this approach will need to modify their own .mailcap and .mime.types files.
 - o One can simply copy the FASTrek executable, a C shell script, by itself. It allows users to run Scientific Expeditions, but Remote Collaboration and the GUI will not be available. Users will need to modify their .mailcap and .mime.types files.

Once the executables are online, FASTtreks can be run by clicking on a link. Several types of files can have the FASTrek suffix, and FASTrek will determine the file type and appropriate action. Types include:

- A tarred, gzipped file containing data and one or more FAST scripts. When one of these files is read, FASTrek unpacks the files, creates a subdirectory in a standard location for storing the script files, creates several other files in the subdirectory, and starts FAST with the script designated as the startup script, which reads the data.



FASTrek reads an archive containing data and scripts, and starts FAST with a setup script, which loads the data.

- A single FAST script. In general, all the scripts associated with a particular dataset are sent with the dataset, and placed in a subdirectory of /tmp. The html document should contain links to this location. Additional scripts for FASTtreks can be developed and made available individually. Each script must contain the line: #FASTrekscript [scriptname].FASTrek In order to be

recognized by FASTtrek. When using the utility for assembling a dataset into a FAST Expedition, this line is added automatically. If the script is created separately the line must be added by hand.



Scripts for viewing the dataset, such as this loop through scalar values (3), are a second FASTtrek type.

- Files containing a command to be performed. These include exiting FAST, saving the data used in the FAST Expedition to a permanent directory, cleaning up temporary files, and running a Remote Collaboration session. These files are created under /tmp when the dataset is read, and are used to control the FASTtrek with hyperlinks. A hyperlink to /tmp/FASTexpeditions/FASTexit.FASTtrek, for example, will send a file containing the single line "FASTexit" to the FASTtrek executable, which will then terminate FAST.



When FASTtrek loads a dataset, it creates a third type of FASTtrek file: temporary files containing commands, which are stored in a standard location. Links to these files on the HTML document provide an interface to FAST.

Comparison of Using Movies and FAST Expeditions

The Acoustic Doppler Currents Profile (4) MPEG movies in the Example Movies of Scientific Data illustrate the current trend to display animated data in compressed pixel form. Each movie contains a currents profile, displaying the direction and speed of currents at 30 depth levels in the ocean. The direction of currents is represented by arrows, and the arrows' length and color represent the speed of the current. Each MPEG animation represents one profile, and each movie requires the transfer of approximately 2 MBytes of data for 89 frames of movie.

Making this data in animation form online is a vast improvement over text-only files. To illustrate the next step, we have generated a similar dataset for viewing with

FAST. Our dataset contains 30 profiles. The dataset contains vector and scalar values for the current direction and speed, respectively. FAST can display these values as colored arrows of different lengths, but it is not limited to that mode of display.

The FAST Expeditions to explore equivalent data illustrate

- The data to be transferred can be reduced dramatically: the entire FAST Expedition, containing 30 profiles, is less than half the size of one MPEG movie.
- The viewer can view the data in a much richer variety of ways.
 - The data can be viewed in 3D to see the direction of the vectors. *One cannot tell the direction of 3D vectors in space with a single view (as in the movies).* With FAST, one can rotate the viewing position to determine the direction of the 3D vectors. (Running the Stereo script, for use with Crystal Eyes stereo glasses, one can determine the direction of the vectors without rotating the view.)
 - All of the data in the movies can be viewed at once to better view correlations in the various dimensions (depth, day, and time of day).
 - In addition to "sweeping through time" as in a movie, the viewer can sweep through the other dimensions.
 - The viewer can interactively highlight features through color selection and other techniques.
- The viewer can do his own "what if" analysis of the data.

Guided Expeditions Into the Ocean Currents

Load Data

In addition to these Expeditions, you can elect to conduct your own expedition into this data. For example, you could view the day-of-month vs. time-of-day surfaces while sweeping through the depth direction, or you could view the depth vs. time-of-day surfaces while sweeping through the day-of-month direction. The time-of-day dimension has been compressed to make these movies simpler. You may wish to re-expand it.

You can view the following modes one at a time or combine them. I recommend the combination of "Time sweeping on" and "Stereo" and the combination of "flyby" and "viewing as a surface that goes through the ends of the vectors".

The Stereo mode is for use with Crystal Eyes glasses.

Please wait for the prompt to "try an expedition" before selecting each option

- Time sweeping on - This permits viewing as a movie through time. This is the mode that compares directly with the movies. While the movie is playing, try rotating to get a better view of 3D. Also, try panning through the days of the month. If you lose the picture off the screen, Reset the view to the original position.

- Time sweeping off – This stops viewing as a movie through time
- Reset the time of day to zero
- View the surface that goes through the ends of the vectors
- Initiate a flyby over the depth vs. day-of-month surface
- Stop the flyby over the depth vs day-of-month surface
- Reset the orientation to the original orientation
- Go back to viewing the plain vectors
- Stereo – This creates a full screen stereo image for use with Crystal Eyes.
NOTE! – when through viewing the stereo scene, press ENTER to exit from full screen mode
- Mono – This returns from stereo to mono
- Exit FAST
- Save Data
- FASTcleanup

Other Features

In addition to running FAST expeditions, FAST users can use the FASTtrek tools to run Remote Collaboration sessions, and to create their own Scientific Expeditions.

Remote Collaboration (5)

When FASTtrek is passed a file containing the command *FASTremote*, it creates a pipe from which FAST will read script commands. It also creates files containing the commands *FASTmaster*, *FASTconnectmaster*, and *FASTdisconnect*, to control FASTtrek. When a user becomes master, and other users connect, FASTtrek calls the utilities *FASTtalkserver* and *FASTlistento*, to create socket connections between the machines. *FASTtalkserver* reads FAST commands as they are generated by FAST, and sends them to the slave machines, where *FASTlistento* handles receiving the commands and piping them to FAST.

From the user's point of view, the only technical hurdle is inserting a line in the */etc/services* file (which requires root privileges):

```
fastd      5001/tcp
```

Once that is done, to run a collaborative session one simply clicks on FAST remote, then on FASTmaster or FASTconnectmaster. To switch, the user clicks on the other choice. Clicking on FASTdisconnect severs connections.

The simplicity of this interface makes using Mosaic desirable for remote collaboration any time remote collaboration is done, and not only for connecting with scientists supplying FAST Expeditions on the Web. For local use, an html page linked to a FASTremote file and to the /tmp location where FASTtrek will put FASTmaster and FASTconnectmaster is provided in the archive.

To try Remote Collaboration, you must have the entry in /etc/services described above. Then, contact a colleague. Each Collaborator should run FAST, load the same data, and then select Initialize FAST Remote. When remote setup is initialized, select from:

- Become Master
- Become Slave
- Sever Connections
- FASTexit

- Save Data

- FASTcleanup

Creating Scientific Expeditions for use with FAST

For users running web servers, creating FAST expeditions is easy. A awk script, FASTtar.awk is provided. To create an expedition, invoke FASTtar.awk, passing it the names of the FAST scripts for the expedition. The awk script will create soft links to the datasets read by the scripts, and assemble all the scripts and the data in a gzipped tar file. If Remote Collaboration is desired, a FASTremote file can be included. In addition to creating the FASTtrek file, the awk script makes a skeleton home page with hyperlinks to the scripts already on it.

The National Goals

These FAST Expeditions were developed in support of a proposal to the NSA, NCSA, and NCGA to define the Scientific Expeditions as a way to improve use of the information superhighway, and to bring Scientific Expeditions into the schools. Specifically, the goals are:

The Proposed Target

A capability as good or better than the FAST Expedition approach outlined here.

Proposed National Goals

Goal 1

- The "scientific expedition" shall be available to
- Every high school and above by the end of 1996

- Every school by the end of 1998

Goal 2

NASA, EPA, and similar research facilities, shall have information available on the Information Superhighway in a format like the Scientific Expedition by the end of 1996.

To learn more about FAST Expeditions and the National Goals, see the National Goals Home page.

Notes

1. Flow Analysis Software Toolkit (FAST) is currently under development by members of the Numerical Aerodynamics Simulation (NAS) Division at NASA Ames Research Center, Moffett Field, CA 94035-1000. See the FAST home page for information on FAST, including how to get FAST. The URL is:

<http://www.nas.nasa.gov/FAST/fast.html>

2. *FAST on HDTV Monitor*. Visualization by John West, FAST Development Team, Sterling Software, Inc. Grid and solution courtesy of Dr. David Huddleston and Dr. Bharat Soni, NSF Engineering Research Center for Computational Field Simulation, Mississippi State University.

3. The animation shown is from *Effect of a Canard on Vortex Structure and Pressure* by Eugene L. Tu, RFA/NASA Ames.

4. Acoustic Doppler Currents Profile (ADCP) MPEG movies are produced daily by Cheng Tang for the REINAS project at University of California, Santa Cruz. These movies display ocean currents profile data collected from MBARI's M1 buoy, data courtesy of Dr. L. Rosenfeld.

5. The Remote Collaboration technology was developed by Val Watson and John West.